Intern. J. Neuroscience, 114:1183–1193, 2004
Copyright © Taylor & Francis Inc.
ISSN: 0020-7454 / 1543-5245 online
DOI: 10.1080/00207450490475643

Taylor & Francis
healthsciences

POWER INCREASES WITHIN THE GAMMA RANGE OVER THE FRONTAL AND OCCIPITAL REGIONS DURING ACUTE EXPOSURES TO CEREBRALLY COUNTERCLOCKWISE ROTATING MAGNETIC FIELDS WITH SPECIFIC DERIVATIVES OF CHANGE

E. W. TSANG
S. A. KOREN
M. A. PERSINGER

Behavioral Neuroscience Laboratory
Sudbury, Ontario Canada

A total of 11 men and women were exposed for 5 min each to six different temporal configurations of pulsed magnetic fields that were delivered through serial activation of 8 solenoids in a counterclockwise direction around the head within the horizontal plane above the ears. Twenty-second samples of quantitative electroencephalographic activity within the delta, theta, lower alpha, upper alpha, beta, and gamma regions were collected after each configuration had been activated for 2.5 min. Only the circumcerebral presentation of the first pulse for 25 ms followed by an acceleration of +2 ms to each of the other 7 solenoids (the last duration = 11 ms) resulted in a significant increase in power within the gamma range (35 Hz to 45 Hz) over both frontal and occipital lobes but not over the parietal or temporal lobes. These results suggest topical application of specific spatial-temporal configurations of magnetic fields may affect the recursive creation of the rostral-caudal waves of cohesive fields that might produce consciousness.

Keywords brief exposures, circumcerebral, derivative of change, electroencephalogram, gamma frequencies, human, magnetic field

Received 21 November 2003.

Address correspondence Dr. M. A. Persinger, Behavioral Neuroscience Laboratory, Departments of Biology and Psychology, Laurentian University, Sudbury, Ontario, Canada P3E 206. E-mail: mpersinger@laurentian.ca

Human consciousness is likely to be an emergent property (Edelman, 1989) of cohesive electromagnetic fields generated by the synchronous firing of large numbers of neurons (McFadden, 2002). Llinas and Pare (1991) have measured large transcerebral electromagnetic fields originating from intracortical activity. These "cohesive" manifolds appear to be recursively created between the frontal to occipital lobes every 15 ms to 25 ms and would be associated with the "40 Hz" rhythms associated with consciousness (Jeffreys et al., 1996). This electromagnetic configuration appears most dominantly in the waking state and during dreaming.

McFadden's (2002) model suggests that most neurons are in sensitive to the brain's electromagnetic field. Only the information represented by neurons that fire in synchrony is likely to generate sufficiently large perturbations of the brain's electromagnetic field to influence nerve firings in a few neurons and hence modulate behavior. If one of the intrinsic patterns of firing (as an emergent property within the cerebral cortices) is between 15 ms and 25 ms (or between 40 Hz and 66 Hz) then, the application of weak magnetic fields with the appropriate complexity (Tononi & Edelman, 1998) and temporal derivatives might increase (through a resonance-like process) the power within this range of electroencephalographic activity.

Cook et al. (1999) had found that the successive but brief circumcerebral applications of weak (1 microTesla) magnetic fields along the horizontal plane resulted in distortion of subjective time when a specific configuration of a type of frequency-modulated field was employed. The effect was evident only when the sequence of activation of the fields from the 8 solenoids, arranged equally along the horizontal plane, was counterclockwise (from the top) but not clockwise. Counterclockwise application would have moved in the same direction as the left hemispheric cohesive waves but in the opposite direction as the cohesive waves produced in the right hemisphere. The latter direction could produce "interference patterns" as the endogenous and exogenous magnetic fields "collide."

Richards et al. (2002) recorded the quantitative electroencephalographic activity over the left and right prefrontal, temporal, occipital, and occipital lobes in volunteers while each of six different configurations of magnetic fields were applied in a counterclockwise

direction. Although their main interest was to test the hypothesis that the major correlates of the apparent "stream" of human consciousness were recursive transients or serial quanta occurring as second and third derivatives within 1 Hz phase shifts within the 5 Hz to 6 Hz range (Persinger, 1999), they found increased power within the gamma range (35 Hz to 45 Hz) over the *right* hemisphere with some of the configurations that involve the frequency-modulated (or "Thomas") pulse.

METHODS

Subjects

A total of 11 men and women, between the ages of 19 and 50 years, volunteered as subjects. Seven of the subjects were university students; four of the subjects were family members who volunteered because of personal interest. The students received 2% bonus marks for their final grades in a first year psychology course for participation.

Procedure

Each subject was tested individually. The subject was told the experiment was involved with the electroencephalographic effects of relaxation and that electromagnetic fields may or may not be applied. After the subject signed the departmentally approved consent form, the subject sat in a comfortable arm chair that was placed about 2 m from the Grass Model 8-16C electroencephalograph. After silver electrodes were attached by EC2 cream over approximately F7, F8, T3, T4, P3, P4, 01, and 02 (frontal, temporal, parietal, and occipital lobes of the left and right hemisphere, respectively) and referenced to an ear electrode (monopolar measurements), a blind fold and disposable earplugs were applied.

A cloth band was placed around the head to help maintain the electrodes and a strip of velcro was placed over the band. The eight solenoids of the device that delivered the circumcerebral magnetic fields, the Octopus (Cook et al., 1999), were attached to the velcro

so that the first solenoid was over the left frontal region and the eight solenoid was over the right prefrontal region.

After the subject had relaxed and the electroencephalographic record was quiet, with few artifacts, a 20-s baseline measurement was recorded by computer. During the next 30 min each subject received the configurations noted in Table 1. Each configuration was presented for 5 min. For all configurations the frequency-modulated field was generated by a laptop 286 computer. The point durations of each value that composed a voltage was 1 ms. Quantitative electroencephalographic activity was recorded for 20 s after each of the six configurations had been presented for 2.5 min (Richards et al., 2002). At the completion of the study, the equipment was removed from the subject and any questions were addressed.

Circumcerebral Magnetic Fields (Octopus)

Each pair of solenoids of the eight containers (16 solenoids in total) that were placed around the subject's head was constructed from small reed switches. Each container was 3.5 cm wide and 5 cm long. The minor axis of the ellipsoid container (old film canisters) was attached to the Velcro strip. Each pair of solenoids was connected to a custom-constructed control circuit that could be programmed by computer to generate different shapes of fields with different temporal characteristics.

The primary pattern was generated from a DOS file containing a column of numbers between 0 and 255 that represented increments of voltage between –5 and +5 V. Numbers above 127 were positive

TABLE 1. Parameters for the five variables comprising the six configurations of circumcerebral magnetic fields employed in the present study

	Configuration					
Variables	*1*	*2*	*3*	*4*	*5*	*6*
Pattern	FM	FM	FM	FM	FM	FM
Point duration (ms)	1	1	1	1	1	1
Interstimulus (ms)	1	1	1	1	1	1
Commutator rate	100	100	25	25	167	167
Change in rate	+10	–10	+2	–2	+20	–20

polarity whereas those below 127 were negative polarity. Consequently any complexity of shape could be created by this range in the numbers within the row. The frequency-modulated pattern employed in this study was composed of 849 points whose duration was set to 1 ms before the next point was activated. The rise time was 0.1 ms.

Each number was translated into the appropriate voltage by a digital-to-analogue converter. The time between the pulses was also set to 1 ms so that the frequency-modulated pattern was repeated continuously. The third parameter, the commutator time, was the duration each pulse was presented at each pair of solenoids. The fourth parameter was the commutator rate. It was the duration of additional (–, for de-acceleration) or less time (+, for acceleration) in ms that the signal was delivered to the solenoids as each one was successively activated. When each solenoid was activated the intensity near the scalp was between 0.5 microT and 1.5 microT.

The six configurations selected for this study are shown in Table 1. The 100 ms commutator period and the +10 or –10 ms changes in commutator times were derived from previous studies. The 167 ms durations with either +20 ms or –20 ms changes in durations were selected from the hypothesis (Persinger, 1999) that changes within the theta band might mediate changes in consciousness. The range of the functional frequencies for the +20 ms configuration was between 6 Hz and 37 Hz whereas the functional range for the –20 ms configuration was between 3.3 Hz and 6 Hz.

The 25 ms commutator time with +2 ms acceleration was selected because: (1) the successive durations changed between 25 ms and 11 ms that overlapped with functional frequencies between 40 Hz and 90 Hz (the gamma range of the electroencephalogram), and (2) the rotational frequency (numbers of times all eight solenoids were sequentially activated around the head) was about 7 Hz. Both theta and gamma frequencies are generated within the hippocampal formation. We have hypothesized that the hippocampal formation itself or the structures its electrical activities influence may be the "sensor," perhaps by resonance interaction, by which specific patterns of magnetic fields affect brain function. For comparison, the 25 s –2 ms pattern resulted in a durations between 25 ms and 39 ms or 40 Hz to about 25 Hz that would be below the gamma range.

Electroencephalographic Measurements

The filter selections for each channel were set for the standard range between 0.5 Hz and 35 Hz. A 20 s sample of monopolar quantitative electroencephalographic activity, referenced to the ear, was completed simultaneously from all eight leads. The record was obtained while the strip chart was operating simultaneously in order to insure no artifacts contaminated the quantitative measurements.

The machine was interfaced via a custom shielded cable, a parallel analogue shielded interface cable (Nat. Inst. SH100100), and a shielded connector block (Nat. Inst. SCB-100) to a National Instruments PCI-6071E Multi I/O Board computer interface card. The data collection was extracted by a DELL Dimension 8100 Personal Computer on a Windows 2000 Professional Platform. A custom designed user interface or Virtual Instrument (VI) using National Instruments Labview (Version 6.0i-2000) allowed the multichannel sample to be manually recorded to fixed disk.

The digital electroencephalographic recordings were analyzed with a custom programmed software package for Fast Fourier Transforms. The software was compiled under Borland Pascal (version 5.5, 1986). The Fast Fourier Transform utilized three publicly available Pascal software libraries for standard mathematical functions that included FMATH v 2.5: Debord, 2001; FOURIER: Cross & Debord, 1998; and MATRICES v2.1: Debord, 2001.

The frequency spectral outputs from each lead from the four lobes of the two hemispheres for the six patterns were extracted into a single file for five increments of frequencies that included delta (1 to 4 Hz), theta (4.0 to 7.9 Hz), lower alpha (8.0 to 10.4 Hz), upper alpha (10.5 to 13.0 Hz), lower beta (13.1 Hz to 20 Hz), and gamma (35 Hz to 45 Hz) activity. This file was then uploaded to a VAX System for analyses.

Data Analysis

The power from each frequency for each of the eight electrode positions were analyzed as ratios for each of the six configurations. To obtain these scores, the mean of the power for all six configurations for each frequency band and brain region was completed. The

value for each of the configurations was then divided by the mean value for all configurations. This procedure allowed relative changes to be calculated and minimized the obscuring variance associated with individual differences.

The primary analysis was a three way, within-subject, analysis of variance. The within subject (repeated) measures were: lobe (4), hemisphere (2), and configurations (6). The scores for each of the six frequency bands were analyzed separately. Post hoc analysis involved paired *t*-tests. All analysis involved SPSS software on a VAX 4000 computer.

RESULTS

The most significant and conspicuous result involved the gamma band (35 Hz to 45 Hz). There was a statistically significant difference in the relative power between the six configurations [$F(5,50) = 2.51$, $p < .05$; eta-squared = 20%] and several statistically significant interactions between the type of configuration and lobe [$F(15,50) = 3.64$, $p < .001$; eta-squared = 27%], configuration and hemisphere [$F(15,50) = 3.00$, $p < .01$; eta-squared = 23%] and configuration, lobe, and hemisphere [$F(15,50) = 3.78$, $p < .001$; eta-squared = 27%].

As shown in Figure 1, during the 2.5 min after the onset of the configuration presented at each solenoid for 25 ms with a decrease in duration of +2 ms for the activation of each of the successive solenoids, there was at least a 50% increase in the relative power within the gamma range over the prefrontal and occipital lobes but not over the temporal or occipital lobes. Post hoc analysis indicated that the increased power over the prefrontal and occipital lobes compared to the temporal and occipital lobes was similar in both hemispheres and was significantly different than the power for any of the other five configurations that did not differ significantly from each other.

A similar but markedly attenuated increase in the relative power within the beta range was also noted over the prefrontal and occipital region but not over the parietal or temporal lobes. The statistically significant interaction [$F(5,150) = 2.67$, $p < .001$; eta-squared

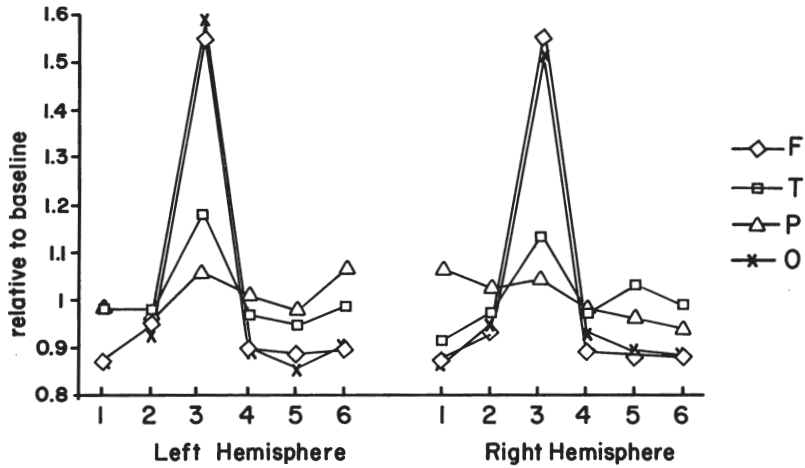

FIGURE 1. Relative changes in power within the 35 Hz to 45 Hz (gamma) range for each of the six configurations (see Table 1) compared to the average of all six configurations over the frontal (F), temporal (T), parietal (P), and occipital (O) lobes for the left and right hemispheres. The values were averaged from 11 subjects.

= 21%] revealed the same pattern. The interaction between phase, lobe, and configuration [$F(15,150) = 1.78$, $p < .04$; eta squared = 15%] was due, according to post hoc analysis, to the relative increase in power within the gamma range over the right temporal lobe for configurations 3 through 6 compared to 1 and 2, which was not evident for the left temporal lobe.

DISCUSSION

The results of this study indicated that a specific configuration of a complex magnetic field generated repeatedly in a counterclockwise direction in the horizontal plane produced a 50% increase in the relative enhancement of power within the 35 Hz to 45 Hz (gamma) band of electroencephalographic activity over the prefrontal and occipital lobes. The particular temporal configuration of this pattern, which progressed as successive jumps of 45° (about 5 cm to 7 cm at the level of the scalp depending upon the circumference of the skull) around the head in a counterclockwise direction with each duration

decreasing in 2 ms units from between 25 through 11 ms, required 144 s (about 6.9 Hz or 414 RPMs) to complete one circumcerebral rotation. For a cranium with a circumference of 60 cm the averaged velocity of the moving field would be about 4.1 m/s or 14.7 km/hr.

The specific configurations of the exogenous field may be optimal for resonance with the endogenous fields because of the physical properties of brain matter. According to empirical measurements (http://www.brooks.af.mil/AFRL/HED/hedr/reports/dielectric) the inductance/m (permeability) of cortical grey matter at 1 kHz (as a result of 1 ms point durations) is about 10^{-2} Henrys (calculated by dimensional analyses from conductivity in S/m). The permittivity for grey matter is 2×10^{-1} Farads/m. Application of the formula $f = 1/(2pi*(LC)^{-1/2})$, the equation for the resonance frequency of a circuit, results in a value of about 7 Hz (Nunez, 1995).

On the other hand, if the values for permittivity and permeability for grey matter for between 40 Hz and 90 Hz (field durations of 25 ms to 11 ms) are solved, the range for resonance frequencies would be between about .1 Hz and .2 Hz. The third author has speculated that the theta and gamma bands of hippocampal activity are modulated by or superimposed on a period of about 10 s (.1 Hz) from thalamic activities whose pacemaker may be the nucleus reuniens (Steriade & Deschenes, 1984). This nucleus is a major thalamic input into the general volume of the entorhinal cortices and hippocampal formation within which the 7 Hz and 40 Hz patterns are generated. It also contributes to the diffuse thalamocortical pathways that modulate cerebral cortical activity.

The marked enhancement of gamma frequencies over the prefrontal and occipital lobes *only* during this configuration may indicate the field interacted with the mechanism by which the gamma activity is repeatedly generated every 20 to 25 ms between the rostral and caudal portions of the cerebrum. Thatcher (1997) has suggested that neural "coherence" is essential for the content of consciousness. The concordance of enhancement within the frontal and occipital lobes bilaterally would be consistent with a model of a resonance effect with the intrinsic periodicity of the recursive waves, putatively considered the "temporal binding factor," created as phase shifts every 10 to 25 ms between the frontal and occipital regions (Llinas & Pare, 1991).

The authors have conceptualized a type of "standing wave" that could be generated by this configuration. For this model the normal steady-state polarity of about 10 mV between the rostral and caudal portions of the cerebrum would behave as a dipole that determines the direction of the rostral caudal movement of the recursively generated temporal quanta of 20 to 25 ms. The serial activation of the counterclockwise pattern approximately seven times per second in conjunction with the cerebral cortices' inductance and reluctance would allow the creation of a residual component within this potential. This component would help synchronize the firing of neurons (and thus the power spectrum) of one of the endogenous frequency bands (40 Hz) of the cortical manifold.

The enhancement of power over the prefrontal and occipital lobes was not likely to have been an artifact of direct effects from the equipment because the effect was only evident with a single temporal configuration. The pattern that began with 25 ms durations and progressively increased to 39 ms did not elicit these changes. Similarly, the configurations that were based on 6 Hz, which increased or decreased progressively by 20 ms, did not produce any powerful changes in the relative power over any of the lobes or hemispheres.

The probability is low that the effect was an artifact of the duration of sitting unless one assumes that sitting blindfolded in a comfortable chair produced this effect for only a few minutes during the middle of a 30-min session. The possibility cannot be eliminated that the relative enhancement of gamma frequencies and beta activity may be associated with this particular configuration represented a *cumulative* effect from this pattern because of the presentation of the first three.

REFERENCES

Cook, C. M., Karen, S. A., & Persinger, M. A. (1999). Subjective time estimation by humans is increased by counterclockwise but not clockwise circumcerebral rotations of phase-shifting magnetic pulses in the horizontal plane. *Neuroscience Letters*, *268,* 61–64.

Edelman, G. N. (1989). *The remembered present: A biological theory of consciousness*. New York: Basic Books.

Jeffreys, J. G. R., Traub, R. D., & Whittington, M. A. (1996). Neuronal networks for induced "40 Hz" rhythms. *Trends in Neurosciences*, *19,* 202–208.

Llinas, R. R., & Pare, D. (1991). On dreaming and wakefulness. *Neuroscience*, *44,* 521–555.

McFadden, J. (2002). Synchronous firing and its influence on the brain's electromagnetic field: Evidence for an electromagnetic field theory of consciousness. *Journal of Consciousness Studies, 9,* 23–50.

Nunez, P. L. (1995). Toward a physics of the neocortex. In P. L. Nunez (Ed.), *Neocortical dynamics and human FEG rhythms* (pp. 68–132). New York: Oxford University Press.

Persinger, M. A. (1999). Is there more than one source of the temporal binding factor for human consciousness? *Perceptual and Motor Skills, 89,* 1259–1262.

Richards, P. M., Karen, S. A., & Persinger, M. A. (2002). Circumcerebral application of weak complex magnetic fields with derivatives and changes in electroencephalographic power spectra within the theta range: Implications for states of consciousness. *Perceptual and Motor Skills, 95,* 671–686.

Steriade, N., & Deschenes, M. (1984). The thalamus as a neuronal oscillator. *Brain Research Reviews, 8,* 1–63.

Thatcher, R. W. (1997). Neural coherence and the content of consciousness. *Consciousness and Cognition, 6,* 42–49.

Tononi, G., & Edelman, G. N. (1998). Consciousness and complexity. *Science*, *282,* 1846–1851.

Copyright of International Journal of Neuroscience is the property of Taylor & Francis Ltd and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.